Effects of Electrostatically Charged Dust on Solar Array Performance in a Simulated Mars Environment

American Institute of Aeronautics and Astronautics
34th Aerospace Sciences Meeting and Exhibit
Reno, Nevada

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January 15-18, 1996

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ABSTRACT

The environment near the Martian surface consists of a low-pressure carbon dioxide atmosphere which probably contains airborne electrostatically charged dust particles. It has been hypothesized that this dust might be attracted to operating solar cells, consequently obscuring light and reducing solar array power output. A Mars environment was therefore simulated and experiments run in order to determine the effects of charged and uncharged dust on solar array performance. Results will be analyzed to evaluate the viability of solar cells in JPL's Mars Pathfinder power system.

INTRODUCTION

The atmosphere of Mars is composed of 95.5 percent CO_2, 2.7 percent N_2, 1.6 percent Ar, .15 percent O_2, and .07 percent CO[1]. Water vapor is virtually absent in the Martian environment. Atmospheric pressure near the surface averages 4.0 torr. Typical temperatures on Mars range from -140° C to 30° C. Martian windspeeds have not been quantified as precisely, but it is thought that windspeed near the Martian surface is nearly always less than 20 m/s. An average value of windspeed would probably be closer to 6 m/s. We also have data on the composition of Martian dust. Elemental analysis has revealed SiO_2 (43.3 percent), Fe_2O_3 (18.2 percent), Al_2O_3 (7.2 percent), SO_3 (7.2 percent) as well as varying traces of other constituents.[2]

JPL is planning to send a lander/microrover package to Mars to make environmental surveys for at least 30 days. The project is called Mars Pathfinder and the launch date is scheduled for December 5, 1996. The lander will be a tetrahedron-shaped module. After impacting upon the Martian surface, three of the lander's sides will unfold to reveal three 11 ft^2 solar arrays which will generate up to 196 W for the Pathfinder power system. The microrover will be equipped with its own solar cells.

A potential problem arises because Martian dust particles acquire electrostatic charges. Particles can become electrostatically charged from UV irradiation or triboelectric

[1]Owen, et al.

[2]Banin, A.

effects. The dryness of the Martian atmosphere probably contributes significantly to dust charging. The charge to mass ratio q/m of a Martian dust particle probably ranges from 10^{-6} to 10^{-4} C/Kg.[3] It is possible that when solar cells are operating in the Pathfinder power system, the electromagnetic field set up could interact with charged dust particles to attract such dust to the surface of the arrays. If this were to happen, light would be obscured and power output of the solar arrays would decrease. Therefore, a simulation of a Martian atmosphere was prepared and solar cell performance was monitored under varying conditions. Atmosphere dust loading, insolation, and UV irradiation intensity were examined as independent variables.

MATERIALS

Tests were run inside a cylindrical stainless steel vacuum chamber, 45 ft^3 in volume, borrowed from JPL's Dr. Arthur Lane. The vacuum chamber was equipped with swinging doors at either end, ports for windows and feed-thrus, and plumbing for backfilling and watercooling. A Welch mechanical vacuum pump with a 1 hp motor was used to pump down to about 3 torr. Inside the chamber, an aluminum plate was placed in a horizontal plane, 15 in. above the bottom of the chamber. This plate served to divide flow and provide a "ground" surface on which to place samples and instrumentation. Aluminum was chosen for this plate due to its low cost and light weight. With the aforementioned gas composition, and a pressure between 3 to 5 torr, outgassing was not considered to be a serious problem; therefore, aluminum was used on more than one occasion inside the chamber.

An electric fan was used to generate wind inside the chamber. A 14 in. diameter, 7-bladed, backwardly curved, aluminum axial-flow fan blade was used with a 1 hp 208 VAC, 3-phase GE motor. The fan was placed underneath the ground plate to create wind as shown in figure 2. No type of flow straighteners were used predominately for reasons of simplicity. In addition, ground effects on Mars' surface should be expected, so straightening flow is not necessarily desirable. The wind speed dictated by the fan's performance, the CO_2 fluid properties, and the chamber geometry was 1 m/s. Windspeed was measured with the use of a drogue wind gauge. This speed was thought to be adequate for two reasons: it was sufficient to circulate airborne dust, it was on the order of the average Martian wind speed, and clearing of solar arrays by Aeolian effects was not being tested. It has been shown

[3] Wang

that windspeeds of at least 35 m/s are necessary to clear dust off of solar arrays.[4]

The atmosphere used was hone-dry CO_2 purchased commercial ly. This gas was guaranteed to contain less than 10 ppm of water, and according to the supplier usually contains about 4 ppm H_2O. The overall CO_2 purity was 99.99 percent, which was more than pure enough to simulate a Martian atmosphere. No evidence has been found that would suggest that electrostatic dust precipitation would depend on the other trace gases in Mars' atmosphere, so an exact simulation was not a concern.

Two types of dust were considered for the simulation. First, a sample of palagonite was borrowed from Ted Roush at NASA Ames. This dust was mined from a Hawaiian volcanic region and has strong chemical. similarity to actual Mars dust. However, the sample has a mean dust. size of about .15 mm[5]. Another sample was obtained with a mean size of about 2 microns. This sample was powdered potter' clay (Carbonale Red) , which is readily available and inexpensive. Experience gained by Dr. Ron Greeley at NASA Ames's Mars wind tunnel (MARSWIT) tells us that size should affect electrostatic charging more than chemistry. Furthermore, particles with greater surface area to volume ratios attenuate more light. Therefore, the potter's clay was selected for the experiment.

Finally, the solar cells used were ASEC GaAs solar cells. The array was a square of four (4) cells, each of which was square, 2 cm on a side. Only four cells were used because the limit of the mass instrumentation, a Mettler AE-100 microbalance, was 20 g. The solar array, including its backing and terminals, measured 18.653(0) g. The light source for the array was a 250 W halogen light bulb, which provided 6.58 mW/cm^2 of insolation.

METHOD

The amount of' dust in the Martian atmosphere is given by:

$$N=N_O\tau\exp(-z/h)$$

where N is dust concentration in particles per cm^3, No is surface dust concentration equal to 6 particles per cm^3 for **2** micron dust, τ is optical opacity, **z** is altitude in km, and h equals 10 km.[6] For this experiment, ground level. (z=0) concentration was desired so dust concentration was a linear

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[4]Gai er, et al .

[5]Roush

[6]Cri sp

function of optical opacity. Typical values of 7 on Mars are $\tau \approx 1$; worst. case values (dust storm) would be $\tau \approx 5$. Knowing the density of the dust, simul ant to be 2.8 g/cm^3, different masses of dust were chosen to correspond to opt ical opacities ranging frOm $\tau = 1$ to T=5, initially. Later, greater dust concentrate ons were used in an effort to observe an obscuration effect. Dust. masses were loaded into a dust hopper and placed in the chamber. The dust hopper was supplied with CO_2 from the backfill line. Dust was dispersed by injecting the hopper with a burst of CO_2 that forced the dust out through a fine screen at. the top of the hopper. Sand (size >> 2 micron) was also placed in the hopper to break up clumped dust as it was ejected. This method was devised and used successfully in the past by Rod Leach at MARSWIT. (. .

Atmospheric composition was obtained by pumping the vacuum chamber full of air down to 1 torr and then backfilling with CO_2 to 200 torr. This provided a purity of 99.5 percent with water content at less than 20 ppm. This gas was then pumped down to 3 to 5 torr. The chamber was subsequently sealed and tests were run for time durations of Up to 85 minutes. The chamber was leak tested with a helium leak detector and ultimately it proved to leak at a rate equivalent to 500 millitorr of pressure per day. Electrostatic precipitation should not depend significantly on pressure variations on that order, so the chamber was not pumped down while tests were run. This greatly simplified the mechanical design of the vacuum system.

During tests, the fan motor and halogen light heated up the gas inside the chamber. However, since CO_2 at 5 torr is a poor conductor of heat, the array temperature rose slowly. Chamber temperature ranged from 16° C to 25° C during testing, with the increase due to radiant heating. Temperatures in this range will be approached near midday on Mars. Since solar cell performance is degraded by heating, our results should be considered as a worst case scenario. Nevertheless, solar array temperature was monitored closely. At about 5 torr, overheating of equipment was a major concern. The electric fan had to be water-cooled. Care was taken to make sure that moisture did not leak into the vacuum chamber, since dryness was an important part of the simulation. The liquid fluorescent display of our Mettler AE-100 microbalance also had to be set up outside of' the chamber in order to avoid overheating.

Once al 1 engineering problems were dealt with, experiments were developed and run. First of all, control data was obtained by weighing the solar cells and monitoring short-circuit current (I_{sc}) without insolation or UV irradiation and with no wind or dust in the chamber. Then, wind was created and stability of the system was observed. Next, white light was applied to the cells and performance readings were taken. Dust was then dispersed into the chamber and open-circuit voltage (VW) , I_{sc}, and cell temperature were monitored while wind was present . After a period of time, the wind was stopped and the halogen light was turned off. Dust was allowed to settle and then final readings were taken. This process was repeated for time periods of 20 and 85 minutes, both with the same settling time of 10 minutes at the end. Next, similar tests were run with the addition of dust ionization. A 500 W mercury arc lamp was used to expose the dust to W radiation; only dust which circulated through the chamber was directly exposed to the UV source. In addition, a .025 in. tungsten wire carrying 3.2 A of current was used as a hot emitter. Finally, 36 V of voltage bias was applied to the array in an effort to magnify attractive forces between the array and airborne dust. These measures established a probability of electrostatic dust charging.

RESULTS AND DISCUSSION

Tests failed to show any sign of electrostatic dust precipitation. Timed trials run with dust. and ionization measures applied showed slight decreases in cell performance (see fig. 1). However, solar cell temperature rose with time during the trials (fig. 2) . Hence, the reduction in power output cannot be attributed to dust deposition. During all trials, masses of dust. deposited on the 16 cm^2 solar array were less than .1 mg. Independent tests in STP air indicated that masses of dust (deposited on arrays) on the order of 10 mg would be necessary to noticeably decrease short-circuit current (fig. 5) . This suggests that temperature rise, and not dust precipitation, is responsible for the slight changes observed. When extreme amounts of dust, ($\approx$150 mg) were dispersed in the chamber, the results were similar to the ones depicted in figure 1. Such quantities of dust correspond to impossible optical opacities, yet still did not appear to effect photovoltaic output.

Possible sources of error can already be identified. First of all, measurement of" the quantity of dust. airborne in the vacuum chamber was not feasible, so data on that independent variable is largely an estimate. Error could arise in the transferal of dust to the dust. hopper after it is initially weighed. In addition, the CO_2 backfill jet cannot eject all of the dust in the hopper so additional uncertainty is added there. The halogen light source used was run off of standard 110 V building electricity. Such a power source can be expected to fluctuate due to voltage spikes, surges, etc. Therefore, small fluctuations in sell.a~ cell performance cannot be attributed to dust precipitation with certainty. However, this experiment was not designed to identify small variations in cell. performance. Finally, the fact that the solar array temperature changes during the test requires a correction (see figs . 3 & 4) . In all, though, there is no reason to think that the qualitative results produced are anything but valid. Correction factors would have to be determined if precise cell performance was to be predicted.

CONCLUSIONS

A satisfactory simulation of the Martian surface was obtained. Pressure, temperature, gas composition, and windspeed were all set at typical Martian values. The experimental apparatus developed was kept simple and produced at a low cost. Due to the vacuum chamber's size and the flexibility of the system, the simulation could be used in the future for a variety of experiments.

In all of the experiments run, there was no discernible presence of electrostatic effects. Control data agreed with the data obtained from runs with dust and ionization apparatus applied. Solar cell performance was observed to degrade with time, but there were factors other than dust deposition which could be responsible. Finally, extreme conditions were applied in order to accentuate the effects of dust on the solar arrays. Nevertheless, significant dust deposition was not observed. However, the authors recommence that additional. steps be taken in order to quantify dust. deposition due to electrostatic charging. Results may be used to make predictions about the success of photovoltaic power systems in use on Mars.

ACKNOWLEDGEMENTS

The authors wish to thank Caltech SURF for its support of the project. They also express thanks to JPL division 34 for helpful conversions, especially to Roger Williams for advice and countless supplies. Finally, Robert Sullivan and Dr. Ron Greeley of Arizona State University are acknowledged for guidance and use of their wind gauge.

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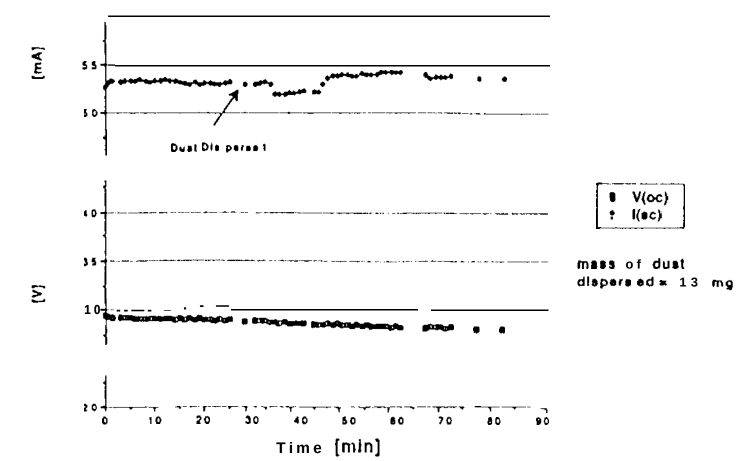

Figure 1. Performance of the ASEC GaAs solar array in the presence of ionized dust

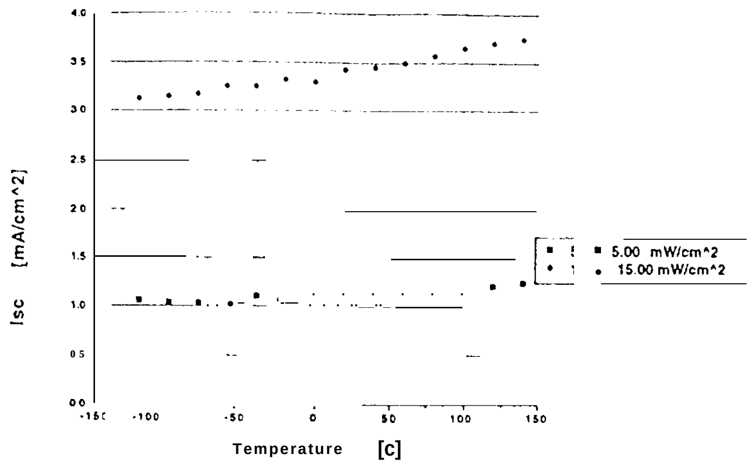

Figure 3. Variation of ASEC GaAs solar cell short-circuit current with temperature

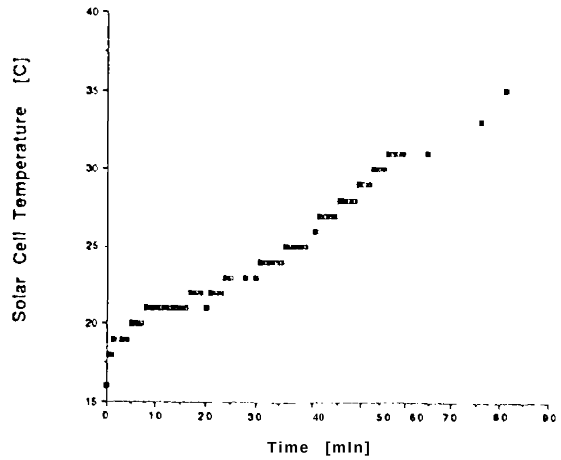

Figure 2. Radiant heating of ASEC GaAs Solar Array during an experiment.

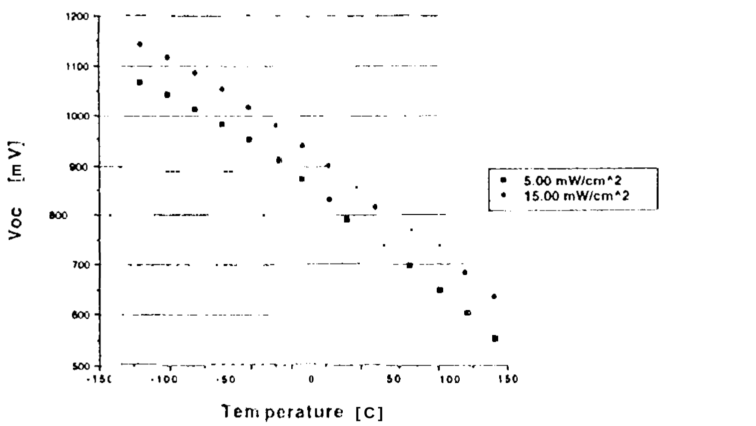

Figure 4. Variation of ASEC GaAs solar cell open circuit voltage with temperature

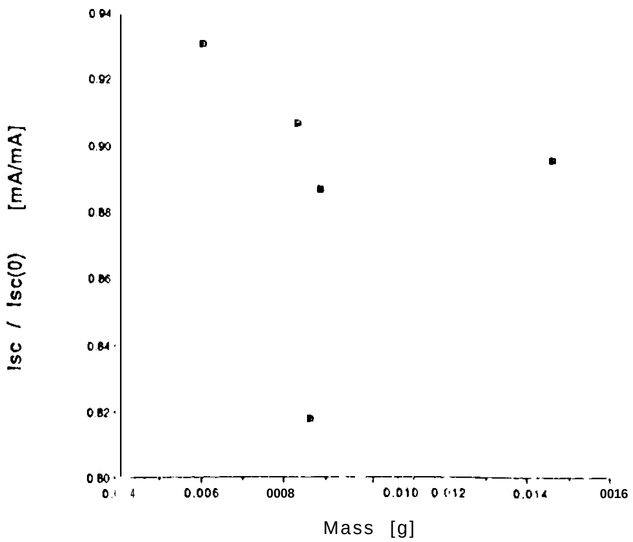

Figure 5. Ratio of final to initial short-circuit current versus mass of dust deposited on cells.